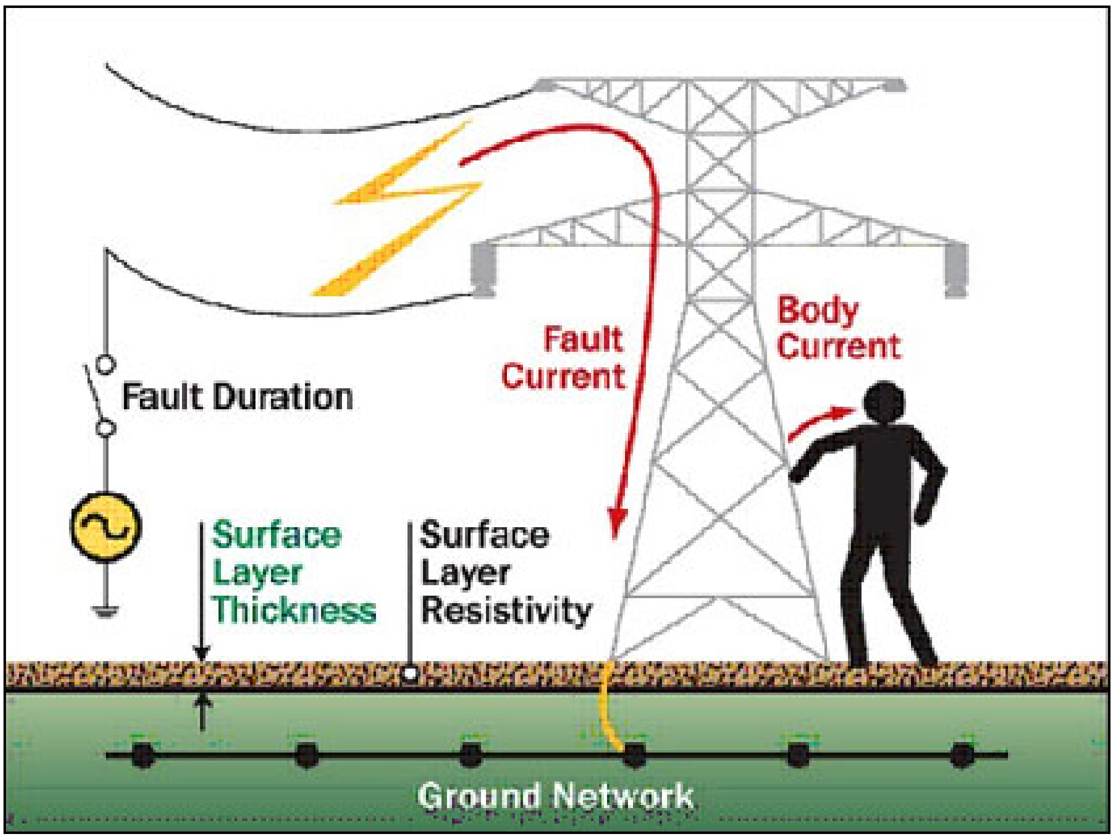
KURDISTAN ENGINEERING UNION

GROUNDING SYSTEM DESIGN AND PLANNING



PREPARED BY
ELECTRICAL ENGINEER
AZAD FARAJ KARIM
I.D NO. ٧٩٠

GROUNDING SYSTEM DESIGN AND PLANNING

١. GENERAL

This training document covers the general technical information on “Earthing System” in residential, commercial and industrial installations, especially for Oil and Gas plants. Detailed and more specialized data and specifications on earthing systems shall be provided to electrical and instrument trainees later during the period of specific course. Sections and paragraphs which are marked with asterisk (*) are more or less specialized and therefore shall be skipped to be offered during the specific course.

١.١. Concept of Earthing Systems

All the people living or working in residential, commercial and industrial installations, particularly the operators and personnel who are in close operation and contact with electrical systems and machineries, should essentially be protected against possible electrification. To achieve this protection, earthing system of an installation is defined, designed and installed according to the standard requirements. Also, earthing system in an oil gas complex shall provide the best protection system against sparking, which could lead to disastrous explosions.

١.١.١. Under earthing system measures, the metal covering body and enclosure of all the equipments are connected to each other as a grid by means of appropriate conductors to establish an equal zero level potential among all the points which may come in contact with the operators. Zero potential, which is built-up and applied to the earthing conductor grid, is produced by special earth wells and their associated accessories.

١.١.٢. Further to protection against the risks of electrification, earthing system is particularly installed in industrial areas where equipments are in possible exposure to explosive material and gas such as oil and gas plants. Difference of electrical potential between the equipment, and machinery is inevitably a source of spark, which definitely leads to an explosion in presence of explosive gases. Therefore a properly installed earthing systems can provide an equal zero electrical potential throughout the plant equipment, thus eliminating the risks of sparks and explosions.

١.١.٣. Lightning, with its high electrical potential, is one of the most serious and dangerous environmental threats, which could cause sever damages to both human life and the installations. Lightning arresters, as part of the earthing system in an installation, are the protective devices, which avert the risks of lightnings.

٢. EARTHING SYSTEM COMPONENTS

Earthing system in an installation is normally comprised of these components:

٢.١. Earth wells and accessories
٢.٢. Earthing grid conductors
٢.٣. Marshalling earth buses (earthing distribution buses)
٢.٤. Earthing wires and cables.
٢.٥. Lightning arresters and accessories

٣. EARTH WELLS AND ACCESSORIES

Earth wells for an specific building or installation are actually the location, where the pure zero potential is provided and practically act as drain pits for any rush current which accidentally appears in the earthing system grid in the event of an earth fault (connection of electrical live parts to the earthing system).

٣.١. Earth Well Components

Depending on the soil conductivity of the location in which the earth wells are installed and also depending on the required technical specifications of the earthing system, different types of components can be used to set up an earth well. Followings are the prime components and accessories of an earth well.

٣.١.١. Earth rod
٣.١.٢. Earth plate
٣.١٣. Earthing clamp
٣.١.٤. Earthing rod coupling
٣.١.٥. Earthing rod tip

٣.١.٦. Earthing rod driving head
٣.١.٧. Carbon bedding mixed with salt
٣.١.٨. Concrete earth pit
٣.١.٩. Concrete slab cover

٣.٢. Earth Rods

Depending on the design for an specific earth well, a number of rods are driven into the ground by means of hammering to form the main earthing electrode in the earth well. In cases where two or more earth rods are to be driven, the individual rods are coupled to each other by means of “earth rod coupling”

٣.٢.١. During the driving of rod into the ground, and to protect the earth rod against impact of hammering, a “driving head” is screwed onto the top of the rod.

٣.٢.٢. For easy and convenient driving of the earth rod into the ground an earth rod tip with sharp point is screwed to the first rod.

٣.٢.٣. Earth rods are used in installation of plain earthing well where, based on design specification of the earthing system the carbon bedding is not necessary and applicable.

٣.٢.٤. Earthing Clamp

Earthing grid conductors are connected to the earth rods, already driven into the ground, by means of earthing clamps. Connection is essentially made by tightly clamping of the grid conductor to the rod using the bolt and nut assembly of the earthing clamp. Earthing clamps and associated bolts nuts, washers, etc. are made of either brass or copper.

٣.٢.٥. Earth Rod Material

Earthing rod and the associated accessories (coupling, tip and head) are made of both steel and copper. A steel core, coated with pure copper to the appropriate thickness, provides the sufficient rigidity for the earthing rod to help driving it straightly into the ground without any harm and bending. The copper coating of the earth rod provides the sufficient conductivity for the earthing system.

٣.٢.٦. Earth Rod Dimensions

Depending on the design specification of the earthing system and the corresponding earthing wells, various earth rods of different dimensions would be incorporated.

٣.٢.٦.١. The range of diameter for the earth rods vary from ١٣ mm to ٢٥mm (١٣mm, ١٦mm, ٢٠mm, ٢٥mm)

٣.٢.٦.٢. Different lengths of earthing rods are used in design and installation of earth wells:

The standard lengths are:

- ١٢٠٠mm
- ٢٤٠٠ mm (٢ × ١٢٠٠ mm)
- ٣٦٠٠ mm (٣ × ١٢٠٠ mm)
- ٤٨٠٠ mm (٤ × ١٢٠٠ mm)

The coupling material is essentially the same as the material for the earth rod with respect to the rigidity and the required conductivity.

٣.٢.٧. Earth Rod Tip

The specification and application of this component was already described in section ٣.٢. The earth rod tip material is not necessarily the same as the earth rod itself, as only a rigid quality is essentially required for the tip other than conductivity. Therefore the earth rod tip is primarily made of steel with slight coating of the copper for conductivity purpose as well as protection against corrosion reasons.

٣.٢.٨. Earth Rod Driving Head

The specification and application of this components was already described in section ٣.٢. The driving head material is not necessarily the same as the earth rod itself, as only a rigid and robust quality is essentially required for the driving head to withstand the impact of hammerings. Driving head is practically discarded when the earth rods are all driven and installed in the ground.

٣.٣. Carbon Bedding

Depending on the technical design specification of the earthing system and primarily for soil conductivity reasons of the area where the earth wells are to be installed, the earth rods are embedded in carbon bedding. To install the carbon bedded earth wells, pre-excavation of the ground, to sufficient size and dimension, would be carried out to provide room for the carbon bedding and the earthing components (rods, plates, etc.). To achieve the maximum conductivity for the earth well, an appropriate amount of salt is added to the carbon and mixed before charging into the earth well.

٣.٣.١. Earth Plate

In earth wells with carbon beddings, earthing plates are normally used instead of earthing rods. The earth plate is made of copper and shaped in the following forms:

٣.٣.١.١. Flat rectangular copper plate.

٣.٣.١.٢. Perforated rectangular copper plate (a grate-like framework of copper plate) the standard dimension of the flat rectangular earth plate is normally ١٠٠ × ١٠٠ × ٣ mm. The standard cross section area for the copper rod or copper strips used in construction of the perforated rectangular earth plate is normally ٧٥ sq-mm.

٣.٤. Concrete Earth Pit

To provide access to the earth rod and its corresponding connection to the earthing grid at the top section of the rod, a small pit-like space is fabricated over the earth well, which is referred to as “earth pit”. Earth pit’s side walls are constructed of concrete material to appropriately isolate the earth rod’s top connection from the surrounding soil and protect it for furture reference test and maintenance practices. Earth pits are essentially, constructed flush with respect to the surrounding finished ground.

٣.٥. Concrete Slab Cover

To protect the earth pits against ingression of foreign material, an appropriate concrete cover is provided to be placed atop the earth pit.

The slab-like concrete cover is equipped with a rigid handle for convenient removing and replacement practices.

٤. EARTHING GRID CONDUCTORS

All electrical earth wells in a specific residential, commercial and industrial installation should essentially be interconnected to plant earthing systems form the main earthing grid.

٤.١. Different Types of Grid Conductors

Interconnecting conductor used for the grid are in the following forms:

٤.١.١. Bare copper strip conductor

٤.١.٢. Single core bare stranded copper cable

٤.١.٣. Single core stranded copper cable with PVC sheath

٤.١.٤. Copper strip conductor with PVC covering

٤.٢. As described earlier, the technical specification and design of the form of the earthing system is bound and dependent on various factors such as:

٤.٢.١. Soil conductivity

٤.٢.٢. Soil moisture (dry soil, or wet soil)

٤.٢.٣. Soil condition (natural soil, or concrete)

٤.٢.٤. The grid shall be directly buried in the ground (soil) or it shall run in open trenches (open channels)

٤.٣. Corrosive or Non-Corrosive Soil

Depending on the above mentioned types of installation of the earthing grid, selection of the grid conductor would be one of the following options:

٤.٣.١. Bare copper strip conductor

For direct buried grid in dry and non-corrosive grounds (soils)

٤.٣.٢. PVC-Covered copper strip conductor for direct buried grid in wet or corrosive ground.

٤.٣.٣. Single core stranded copper conductor for direct buried grid in dry, and noncorrosive grounds.

٤.٣.٤. Single core stranded copper conductor with PVC sheath for direct buried grid in wet or corrosive grounds.

٤.٣.٥. Since steel strips/rods/pipes are very rarely used in industrial earthing systems, therefore we shall not go into details for such earthing grid conductors in this document.

٤.٤. Earthing Grid Conductors Dimension

Depending on the design specification of the earthing system, the size of the grid conductors, would be different as followings:

٤.٤.١. For bare or PVC-covered cables, the cross section area of the cable could be either ٣٥mm٢, or ٧٠mm٢, or ٩٥mm٢ depending on the design specification.

٤.٤.٢. For bare or PVC-covered copper strips, the cross section dimension of the strip is normally ٢٥ × ٣mm.

٥. MARSHALING EARTH BUS

To provide easy access to the earthing grid, particularly to make proper and convenient connections of the equipment to the grid, several common connection points in the form of a flat bar of copper material are established and erected through out the grid and referred to as “earthing marshalling points” or “earthing marshalling bus”, or simply as “earth bus”.

٥.١. The main incoming earthing cable connected to the earth bus is branched off from the main earthing grid.

٥.٢. The outgoing earthing cables, connected to the earth bus in one end, shall be connected to the corresponding equipment on the other end.

٥.٣. All the connections of the main incoming and outgoing earth cables shall be made to the earth bus by means of appropriate cable lugs the compression type and zink coating, using bolts, nuts, flat washers and spring washers for well-tight connections.

٦. EARTHING WIRES (CABLES)

Connections between the marshalling earth buses and the equipments are carried out by means of single wires or cables of appropriate size, which are referred to as “earthing wire”, or “earthing link”. The connection between the earthing buses and the earthing grid is also made by means of earthing cables.

٦.١. Earthing wires and cables are used either bare or PVC-covered (preferably bare) and are normally single core of the different cross section area, depending on the design specification. The common range of the cable size used is ١٦mm٢, ٢٥mm٢, ٣٥,٥٠mm٢ and ٧٠mm٢. Earthing wires (cables) of smaller and higher size could be used depending depend on the design specification and requirements.

٦.٢. Connections of earthing wires (cables) on both ends is made by appropriate compression-type cable lugs, fitted with bolts, nuts, flat washer and spring washers for tight connections.

٧. LIGHTNING ARRESTOR AND ACCESSORIES

To protect the installation against the damages which could happen in the event of a lightning strike, special equipment of different installation set-up are used. The prime element of these electrical safety equipment is the lightning arresters which are installed on the highest point of an installation which are most liable to be struck by the lightning. Lightning arresters are actually part of the earthing system of an installation and are, therefore, appropriately connected to the main earthing grid by means of separate purposemade earth wells.

To provide sufficient technical information and training material on protective measures and systems developed to avert the risks of possible lightning, a separate training subject has already been opened up and dedicated to the lightning issue (P/TM/TRG/E.LN/٠٠١) to be offered during the common course sessions. The protect the plant against lightning, a quite separate independent earthing system is installed in the plant which has no interface and connection with the other earthing systems.

٨. EARTHING RESISTANCE

Under fault condition on an specific point in the overall earthing grid and earthing network, a relatively high amount of rush current flows into the earthing system to find its way to the earth wells. The closer an earth well to the fault point, the greater portion of the fault current is absorbed and drained by that well, and the remaining fault current is absorbed by the other nearby earth wells.

٨.١. Based on the specification and location of the fault point, the fault current value can

be calculated and therefore predicted. Four factors are influential with respect to the fault current value.
٨.١.١. The value of voltage applied to the fault point.
٨.١.٢. The pure ohmic resistance of the fault point with respect to the ground, which includes the ohmic resistance of each individual well, as well as the earthing grid conductors and earthing wires and earthing cables.
٨.١.٣. The number of rotating machineries (motors and generators) and their rated power at the time of fault.
٨.١.٤. The distance between the fault point and the rotating machineries.

٨.٢. Earthing Resistance Measurement

Based on the overall electrical specification of an earthing system, established and erected in an installation, computerized measuring of the pure ohmic resistance for any specific point in the earthing network system is practically possible for electrical design engineers using the available software material and software packages. As an alternative to the above-mentioned method, the pure ohmic resistance of the earthing network at a specific point is also practicable by means of an "earth-resistance measuring equipment" or simply "earth tester"
٨.٢.١. Earthing resistance for each individual earth well is measured by means of the earth tester once the earth rods are driven into the ground or once the earthing plates are positioned inside the carbon beddings.
٨.٢.٢. The earthing resistance value measured for each earth well should not be lower than the prescribed value in the design specifications.
٨.٢.٣. In the event of greater earthing resistance that that of deemed and prescribed in the design specification, the number of earth rods should be inevitably increased and more rods shall be driven into the ground.
٨.٢.٤. To drive the additional earth rods into the ground, following alternative ways could be implemented depending on the existing condition of the earthing well due improved.
٨.٢.٤.١. Coupling of additional earth rods to the existing rods already driven, and driving the new arrangement into the ground by means of hammering.
٨.٢.٤.٢. In cases where coupling of additional rods to the existing (already driven) earth rods is not practically possible, the additional rods could be driven somewhere in the close vicinity of the existing earth well to form a separate but interconnected earth well. The overall earthing resistance is actually lower as a result of two earth wells now in parallel.
٨.٢.٤.٣. To achieve a low earthing resistance, the normal practice in design of the earthing system is to introduce three separate earth wells of similar specification in the form of a triangle configuration. Actually the overall earth resistance (with the wells interconnected) shall be one third of the value for each individual well.
٨.٢.٥. Earthing resistance for the lightning protection system shall not exceed ٥ OHM.
٨.٢.٦. Earthing resistance for the power system earthing in power station and power plants shall not exceed ٥ OHM.
٨.٢.٧. Earthing resistance for the electrical earthing (equipment earthing) shall not exceed ٤ OHM.
٨.٢.٨. Earthing resistance for the electronic devices and instrumentations shall not exceed ١ OHM.

٩. TYPES OF EARTHING SYSTEM

In industrial installations, where both electrical and instrumentation equipment are incorporated and installed, three types of earthing system is generally introduced, designed and erected to provide safety and protective measures.

٩.١. Electrical Earthing Systems

The earthing system, which is designed, installed and connected to all electrical machineries and equipment as well as the plant's bulk equipment is called the "Electical earthing system" or "Electrical earthing network"
٩.١.١. The overall earthing resistance of the electrical earthing system should not be

greater than ٤ OHM, no matter which point of the grid is put under measurement.
٩.١.٢. In earthing systems, where bare conductors of the earthing grid is buried directly underground, each section of the underground grid actually acts as an individual earth well, parallel to the existing earth wells, thus contributing in reduction and improvement of the overall earthing resistance.
٩.١.٣. Earthing connections made to the marshaling earth buses, equipment's earth bosses etc. should be carried out with such skill and workmanship to prevent any possible misconnections, which could lead to added earth resistance other than established and required.

٩.٢. Instrument Earthing Systems

In an industrial installation with sophisticated power and electronic equipment, protective measures should be taken to safeguard the instrumentation and the relevant control panels against the sudden high voltages which might hit the earthing system in the event of a fault (short-circuit) in the power circuit of the installation. To achieve this, as a standard design practice, a separate earthing system is defined, designed and installed in such plants. Technical specification, particularly, the installation of instrument earthing system is quite the same as that of electrical system, described in detailed in earlier sections, except for that the earthing resistance should not be greater than ١ OHM throughout the instrument earthing network. Details on instrument earthing system, particularly the different types of instrument earthing shall be offered during the specific course. In this document several concept of instrument earthing is introduced to the trainees of common course period.

- **٩.٢.١.** Sufficient distance should be maintained between the instrument earth wells and the electrical earth wells. Standard distance is at least twice that of the greatest length of the earth rod driven in either the instrument or the electrical well.
- **٩.٢.٢.** Separate earthing marshalling points (Marshalling buses) is defined and installed to be used for independent connections to instrument devices.
- **٩.٢.٣.** Instrument earth buses are generally installed inside the control building where the instrumentation control are installed and centralized.
- **٩.٢.٤.** The metal clad body of the instrument panels, particularly those which accommodate the power supply line, should be connected to the electrical earth system.
- **٩.٢.٥.** Instrumentations installed inside the plant, shall be connected to the instrument earthing system via the shield wires of the corresponding instrument cables.
- **٩.٢.٦.** Instrument earth wells are installed adjacent to the control building.

٩.٣. lightning earthing system

١٠. OUTSTANDING POINTS ON EARTHING SYSTEMS

Regarding the installation and maintenance of an earthing system in an installation, certain outstanding points and notices is worth to be included in this training document document due to high importance of the earthing concept in industrial areas, particularly oil and gas plants.

١٠.١. Earthing Continuity

Once the installation of the earthing system is completed and put into service, under no circumstance should exist an open, disconnected or loose connection within the overall earthing network. In other words, the earthing continuity should essentially be well achieved, maintained and regularly inspected to ensure reliability and establish the safety for both the operators and the equipment.

- **١٠.١.١.** To ensure and achieve a reliable connection to the underground earthing grid, all the branch-off (TEE-OFF) connections to the grid are made by means of copper welding, which is also termed as "Thermoweld connection".

For grid conductors of different sizes, various thermoweld kits and tools of various sizes are manufactured and available in the market.
Themoweld kits comprise of apparatus and provisions for accommodating the cable ends due welded together. Special welding powder (welding material) is charged into the apparatus in appropriate quantity to provide the welding heat. Once the cable ends are fixed in position and the welding powder charged, the sparker tool initiates the welding which takes place very rapidly following a well-enclosed and well-trapped heat

released by chemical reaction.
To ensure and achieve a reliable connection to the above ground earth buses and the corresponding equipment, all connection points should essentially be made by means of compression cable lugs of appropriate size. Cable lugs of smaller or larger size than that of the cable should not be used. To protect the connections against loosening, caused by mechanical impacts or vibration of the nearby machineries, the cable lugs are tightened sufficiently according to the “standard torque”, tables. Spring washers along with flat washers should be incorporated in cable lug connections.

١٠.٢. To protect the above ground connections in the overall earthing network, particularly at marshaling earth buses against the severe environmental conditions such as dust, moisture and corrosive atmosphere, the exposed earthing connections are treated in two ways:

١٠.٢.١. The copper earth buses are lead-plated and the cable lugs, nuts, bolts, washers, etc. used shall be of zink-plated type.

١٠.٢.٢. The copper earth buses are totally with an spread of special silicon grease, and the cable lugs, nuts, bolts, washers, etc. used shall be of zink-plated type.

Note: Even in cases where the earth buses and connection accessories are all lead or zink plated and corrosion resistant, application of silicon grease to the earth buses is recommended for double protection.

- **١٠.٣.** For underground earthing grids, where the PVC-covered grid conductors are used,the thermowelded tee-off (branch-off) points should be essentially covered with appropriate insulating tapes to prevent direct contact with the soil.

١٠.٤. Bulk equipment in an industrial installation, such as separators, steel structures, outdoor electrical equipment, vessels, large and small machineries, etc. are equipped with an appropriate earth connection provision called commonly as “earth boss”.
Earth bosses are normally small projected angle plate welded to the equipment for earthing purposes. The material of the earth boss should preferably be the same as the equipment’s material. Earthing connections to the earth bosses is carried out by means of bolted cable lugs and normally protected with silicon grease against corrosion.

١٠.٥. Earthing cables, branching off from the underground earthing grid, should be conducted aboveground using appropriate PVC or steel cable riser pipes to protect the cable. To protect the pipe-riser against ingression of foreign material, they are filled with appropriate sealing compound material.

- **١٠.٦.** Power transformers shall have separate earthwells installed adjacent to the transformer bay. The transformer earth well is connected to the main earthing network of the plant.
- **١٠.٧.** Lightning protection system shall have separate earth wells installed adjacent to the building which the lightning arresters are installed atop it.
These earth wells shall not be connected to the main earthing network of the plant.
- **١٠.٨.** Power stations and power plants have their own separate earth wells. These earth wells shall be connected to the main earthing system of the plant.

١٠.٩. In power stations and power plants system the earthing wells are separate from the equipment earthing wells. Both power system earthing wells and equipment earthing wells should be interconnected to each other and to the main earthing network of the plant. The minimum distance between the power system earthing and equipment earthing should be twice the length of the longest earth rod driven in the either wells.

- **١٠.٩.١.** Power system earthing provides the protection against the fault (short-circuit) in the generators and transformers. Earth resistance for the power system earthing shall not exceed ٥ OHM.
- **١٠.٩.٢.** Equipment earthing provides the protection against the fault (short-circuit) inside the distribution panels and elsewhere within the electrical earthing grid.
Earth resistance for equipment earthing system shall not exceed ٤ OHM.
- **١٠.١٠.** Earth rods in triangle earth well configuration shall be connected to each other by means of bare copper strip of ٢٥ × ٣mm or equivalent size stranded cable.
- **١٠.١١.** Once a year, during the annual shutdown maintenance practices all the

earthing connections should be inspected, serviced and retightened.

١١ Grounding System Design & Planning

A grounding design starts with a site analysis, collection of geological data, and soil resistivity of the area. Typically, the site engineer or equipment manufacturers specify a resistance-to-ground number. The National Electric Code (NEC) states that the resistance-to-ground shall not exceed ٢٥ ohms for a single electrode. However, high technology manufacturers will often specify ٣ or ٥ ohms, depending upon the requirements of their equipment. For sensitive equipment and under extreme circumstances, a one (١) ohm specification may sometimes be required. When designing a ground system, the difficulty and costs increase exponentially as the target resistance-to-ground approaches the unobtainable goal of zero ohms.

• ١١.١ Data Collection

Once a need is established, data collection begins. Soil resistivity testing, geological surveys, and test borings provide the basis for all grounding design. Proper soil resistivity testing using the Wenner ٤-point method is recommended because of its accuracy. This method will be discussed later in this chapter. Additional data is always helpful and can be collected from existing ground systems located at the site. For example, driven rods at the location can be tested using the ٣-point fall-of-potential method or an induced frequency test using a clamp-on ground resistance meter.

• ١١.٢ Data Analysis

With all the available data, sophisticated computer programs can begin to provide a soil model showing the soil resistivity in ohm-meters and at various layer depths. Knowing at what depth the most conductive soil is located for the site allows the design engineer to model a system to meet the needs of the application.

• ١١.٣ Grounding Design

Soil resistivity is the key factor that determines the resistance or performance of an electrical grounding system. It is the starting point of any electrical grounding design. As you can see in Tables ٢ and ٣ below, soil resistivity varies dramatically throughout the world and is heavily influenced by electrolyte content, moisture, minerals, compactness and temperature.

Type of Surface Material	**Resistivity of Sample in Ohmmeters**	
	Dry	**Wet**
Crusher granite w/ fines	١٤٠ x ١٠٦	١,٣٠٠
Crusher granite w/ fines ١.٥”	٤,٠٠٠	١,٢٠٠
Washed granite – pea gravel	٤٠ x ١٠٦	٥,٠٠٠
Washed granite ٠.٧٥”	٢ x ١٠٦	١٠,٠٠٠
Washed granite ١-٢”	١.٥ x ١٠٦ to ٤.٥ x ١٠٦	٥,٠٠٠
Washed granite ٢-٤”	٢.٦ x ١٠٦ to ٣ x ١٠٦	١٠,٠٠٠
Washed limestone	٧ x ١٠٦	٢,٠٠٠ to ٣,٠٠٠

Asphalt	٢ x ١٠٦ to ٣٠ x ١٠٦	١٠,٠٠٠ to ٦ x ١٠٦
Concrete	١ x ١٠٦ to ١ x ١٠٩	٢١ to ١٠٠

Soil Types or Type of Earth	**Average Resistivity in Ohm-meters**
Bentonite	٢ to ١٠
Clay	٢٠ to ١,٠٠٠
Wet Organic Soils	١٠ to ١٠٠
Moist Organic Soils	١٠٠ to ١,٠٠٠
Dry Organic Soils	١,٠٠٠ to ٥,٠٠٠
Sand and Gravel	٥٠ to ١,٠٠٠
Surface Limestone	١٠٠ to ١٠,٠٠٠
Limestone	٥ to ٤,٠٠٠
Shale's	٥ to ١٠٠
Sandstone	٢٠ to ٢,٠٠٠
Granites, Basalt's, etc.	١,٠٠٠
Decomposed Gneiss's	٥٠ to ٥٠٠
Slates, etc.	١٠ to ١٠٠

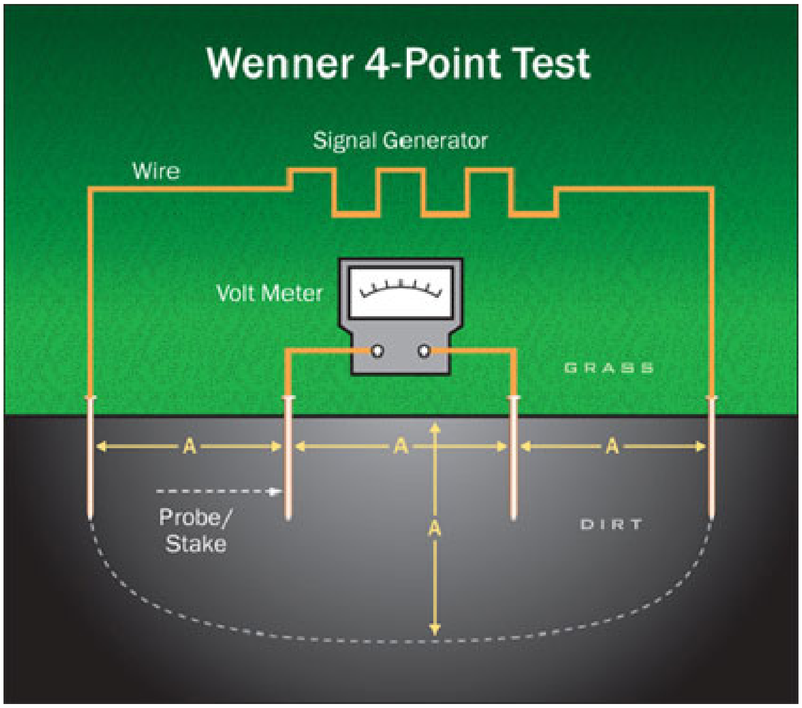
١١.٤ What Is Soil Resistivity Testing?

Soil resistivity testing is the process of measuring a volume of soil to determine the conductivity of the soil. The resulting soil resistivity is expressed in ohm-meter or ohm-centimeter.

Soil resistivity testing is the single most critical factor in electrical grounding design. This is true when discussing simple electrical design, to dedicated low-resistance grounding systems, or to the far more complex issues involved in Ground Potential Rise Studies (GPR). Good soil models are the basis of all grounding designs and they are developed from accurate soil resistivity testing.

١١.٤.١ Wenner Soil Resistivity Testing and Other ٤-Point Tests

The Wenner ٤-point Method is by far the most used test method to measure the resistivity of soil. Other methods do exist, such as the General and Schlumberger methods, however they are infrequently used for grounding design applications and vary only slightly in how the probes are spaced when compared to the Wenner Method.



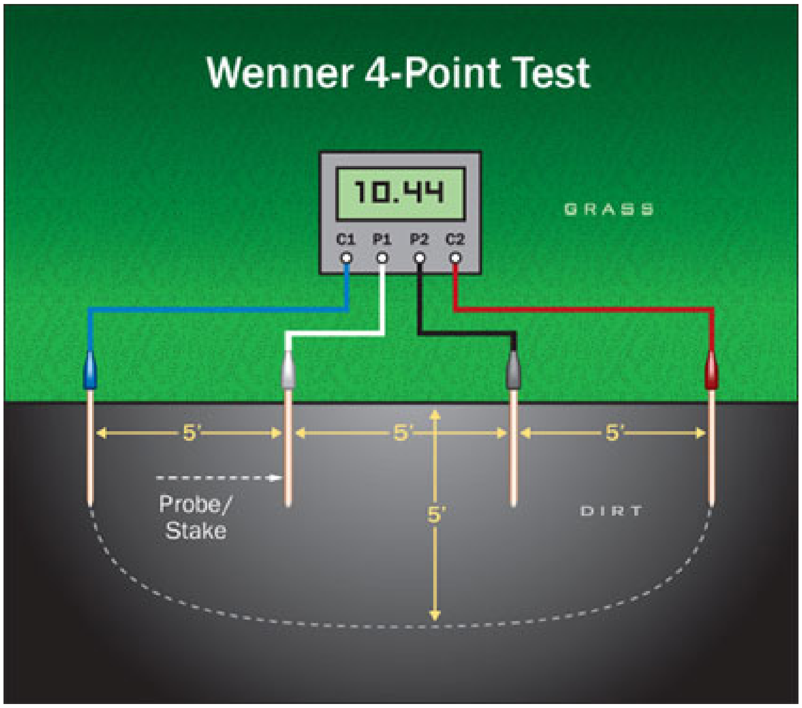
Electrical resistivity is the measurement of the specific resistance of a given material. It is expressed in ohm-meters and represents the resistance measured between two plates covering opposite sides of a ١ m cube. This soil resistivity test is commonly performed at raw land sites, during the design and planning of grounding systems specific to the tested site.

The soil resistivity test spaces four (٤) probes out at equal distances to approximate the depth of the soil to be tested. Typical spacings will be ١', ١.٥', ٢', ٣', ٤.٥', ٧', ١٠', etc., with each spacing increasing from the preceding one by a factor of approximately ١.٥, up to a maximum spacing that is commensurate with the ١ to ٣ times the maximum diagonal dimension of the grounding system being designed, resulting in a maximum distance between the outer current electrodes of ٣ to ٩ times the maximum diagonal dimension of the future grounding system. This is one "traverse" or set of measurements, and is typically repeated, albeit with shorter maximum spacings, several times around the location at right angles and diagonally to each other to ensure accurate readings.

The basic premise of the soil resistivity test is that probes spaced at ٥' distance across the earth, will read ٥' in depth. The same is true if you space the probes ٤٠' across the earth, you get a weighted average soil resistance from ٠' down to ٤٠' in depth, and all points in between. This raw data is usually processed with computer software to determine the actual resistivity of the soil as a function of depth.

١١.٤.٢ Conducting a Wenner ٤-point (or four-pin) Soil Resistivity Test

The following describes how to take one "traverse" or set of measurements. As the "٤-point" indicates, the test consists of ٤ pins that must be inserted into the earth. The outer two pins are called the Current probes, C١ and C٢. These are the probes that inject current into the earth. The inner two probes are the Potential probes, P١ and P٢. These are the probes that take the actual soil resistance measurement.



In the following Wenner ٤-Point Test Setup diagram, a probe C١ is driven into the earth at the corner of the area to be measured. Probes P١, P٢, & C٢ are driven at ٥', ١٠' & ١٥' respectively from rod C١ in a straight line to measure the soil resistivity from ٠' to ٥' in depth. C١ & C٢ are the outer probes and P١ & P٢ are the inner probes. At this point, a known current is applied across probes C١ & C٢, while the resulting voltage is measured across P١ & P٢. Ohm's law can then be applied to calculate the measured apparent resistance.

Probes C٢, P١ & P٢ can then be moved out to ١٠', ٢٠' & ٣٠' spacing to measure the resistance of the earth from ٠' to ١٠' in depth. Continue moving the three probes (C٢, P١ & P٢) away from C١ at equal intervals to approximate the depth of the soil to be measured. Note that the performance of the electrode can be influenced by soil resistivities at depths that are considerably deeper than the depth of the electrode, particularly for extensive horizontal electrodes, such as water pipes, building foundations or grounding grids.

١١.٤.٣ Soil Resistance Meters

There are basically two types of soil resistance meters: Low-Frequency and High-Frequency models. Both meter types can be used for ٤-point & ٣-point testing, and can even be used as standard (٢-point) volt meter for measuring common soil resistivity.

Care should always be given when selecting a soil resistance meter, as the electronics involved in signal filtering are highly specialized. Electrically speaking, the earth can be a noisy place. Overhead power lines, electric substations, railroad tracks, various signal transmitters and many other sources contribute to signal noise found in any given location. Harmonics, ٦٠ Hz background noise, and magnetic field coupling can distort the measurement signal, resulting in apparent soil resistivity readings that are larger by an order of magnitude, particularly with large spacings. Selecting equipment with electronic packages capable of discriminating between these signals is critical.

High-Frequency soil resistance meters typically use a pulses operating at ١٢٨ pulses per second, or other pulse rates except ٦٠. These High-Frequency meters typically suffer from the inability to generate sufficient voltage to handle long traverses and generally should not be used for probe spacings greater than ١٠٠ feet. Furthermore, the High-Frequency signal flowing in the current lead induces a noise voltage in the potential leads, which cannot be completely filtered out: this noise becomes greater than the measured signal as the soil resistivity decreases and the pin spacing increases. High-Frequency meters are less expensive than their Low-Frequency counterparts, and are by far the most common meter used in soil resistivity testing.

Low-Frequency meters, which actually generate low frequency pulses (on the order of ٠.٥ to ٢.٠ seconds per pulse), are the preferred equipment for soil resistivity testing, as they do away with the induction problem from which the High-Frequency meters suffer. However they can be very expensive to purchase. Depending upon the equipment's maximum voltage, Low-Frequency meters can take readings with extremely large probe spacings and often many thousands of feet in distance. Typically, the electronics filtering packages offered in Low-Frequency meters are superior to those found in High-Frequency meters. Caution should be taken to select a reputable manufacturer.

١١.٤.٤ Data Analysis

Once all the soil resistivity data is collected, the following formula can be applied to calculate the apparent soil resistivity in ohm-meters:

Soil Resistivity
4-Point Data Interpretation

$\rho = 1.915\ A\ R$

$\rho = 1.915\ (40)\ (4.5)$

$$\rho = \frac{4\pi AR}{1 + \dfrac{2A}{\sqrt{(A^2 + 4B^2)} - \sqrt{(A^2 + B^2)}}}$$

ρ = Resistivity

A = Spacing of Probes

B = Depth of Probes

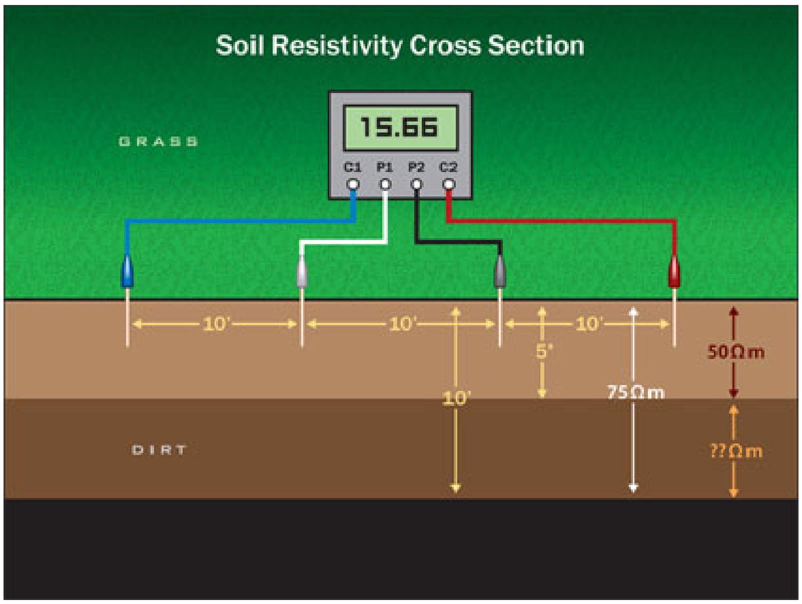
R = Resistance (reading from meter)

If $A > 20B$, then $\rho = 2\pi AR$ **= 1.915 *AR***

For example, if an apparent soil resistance of ٤.٥ ohms is at a ٤٠-foot spacing, the soil resistivity in ohm-meters would be ٣٤٤.٧. Figure ١١ shows the entire soil resistivity formula in detail. One refers to "apparent" resistivity, because this does not correspond to the actual resistivity of the soil. This raw data must be interpreted by suitable methods in order to determine the actual soil resistivity.

١١.٤.٥ Shallow Depth Readings

Shallow depth readings, as little as ٦" in depth, are exceedingly important for most, if not all, grounding designs. As described above, the deeper soil resistivity readings are actually weighted averages of the soil resistivity from the earth surface down to depth, and include all the shallow resistance readings above it. The trick in developing the final soil model is to pull out the actual resistance of the soil at depth, and that requires "subtracting" the top layers from the deep readings. The following figure demonstrates how the shallowest readings impact deeper ones below it.



As you can see in the following diagram, if you have a ٥' reading of ٥٠ ohm-meters and a ١٠' reading of ٧٥-ohmmeter soil, the actual soil resistivity from ٥' to ١٠' might be ١٠٠ ohm-meters (the point here is to illustrate a concept: pre-computed curves or computer software are needed to properly interpret the data). The same follows true for larger pin spacings. The shallowest readings are used over and over again in determining the actual resistivity at depth.

Shallow depth readings of ٦-inches, ١-foot, ١.٥-feet, ٢-feet and ٢.٥-feet are important for grounding design, because grounding conductors are typically buried at ١.٥ to ٢.٥-feet below the surface of the earth. To accurately calculate how those conductors will perform at these depths shallow soil readings must be taken. These shallow readings become even more important when engineers calculate Ground Potential Rise, Touch Voltages and Step Voltages.

It is critical that the measurement probes and current probes be inserted into the earth to the proper depth for shallow soil resistivity readings. If the probes are driven too deep, then it can be difficult to resolve the resistivity of the shallow soil. A rule of thumb is that the penetration depth of the potential probes should be no more than ١٠% of the pin spacing, whereas the current probes must not be driven more than ٣٠% of the pin spacing.

١١.٤.٦ Deep Readings

Often, the type of meter used determines the maximum depth or spacing that can be read. A general guideline is that High-Frequency soil resistivity meters are good for no more than ١٠٠-

feet pin spacings, particularly in low resistivity soils. For greater pin spacings, Low-Frequency soil resistivity meters are required. They can generate the required voltage needed to push the signal through the soil at deep distances and detect a weak signal, free of induced voltage from the current injection leads.

١١.٤.٧ Soil Resistivity Test Location

Soil resistivity testing should be conducted as close to the proposed grounding system as possible, taking into consideration the physical items that may cause erroneous readings. There are two (٢) issues that may cause poor quality readings:

١. Electrical interference causing unwanted signal noise to enter the meter.
٢. Metallic objects 'short-cutting' the electrical path from probe to probe. The rule of thumb here is that a clearance equal to the pin spacing should be maintained between the measurement traverse and any parallel buried metallic structures.

Testing in the vicinity of the site in question is obviously important; however, it is not always practical. Many electric utility companies have rules regarding how close the soil resistivity test must be in order to be valid. The geology of the area also plays into the equation as dramatically different soil conditions may exist only a short distance away.

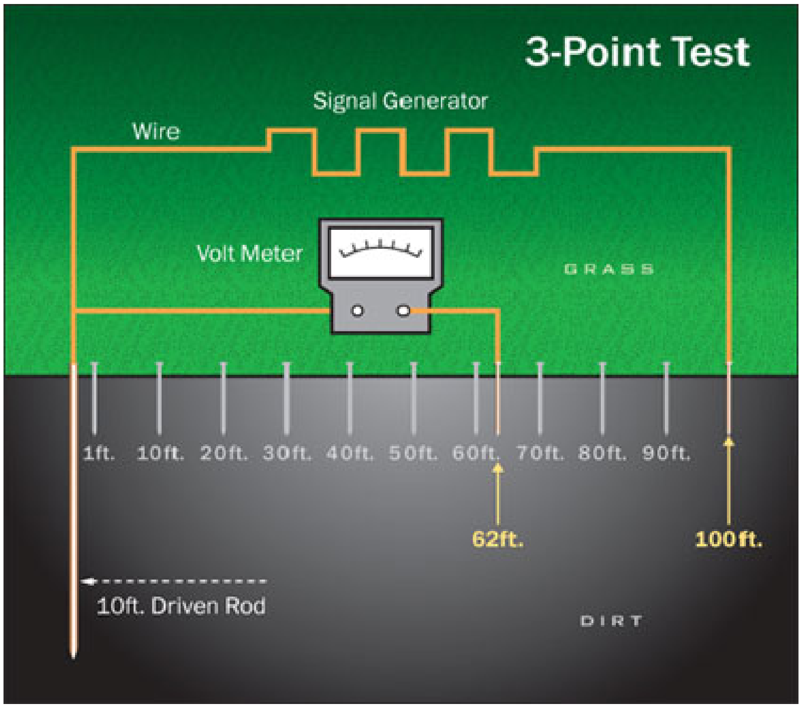
When left will little room or poor conditions in which to conduct a proper soil resistivity test, one should use the closest available open field with as similar geological soil conditions as possible.

١١.٥ How To Do Grounding System Testing

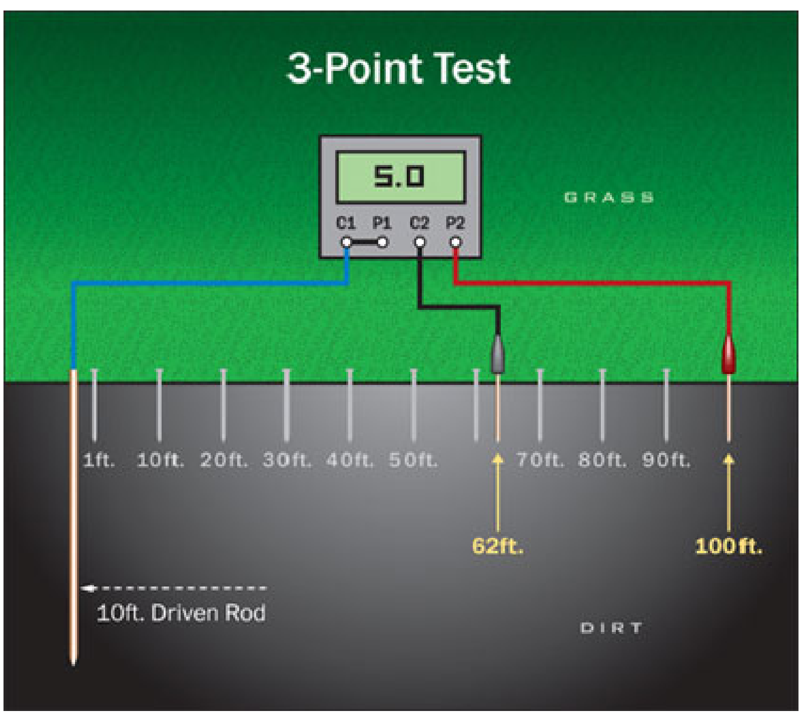
The measurement of ground resistance for an earth electrode system is very important. It should be done when the electrode is first installed, and then at periodic intervals thereafter. This ensures that the resistance-to-ground does not increase over time. There are two (٢) methods for testing an existing earth-electrode system. The first is the ٣-point or Fall-of- Potential method and the second is the Induced Frequency test or clamp-on method. The ٣-point test requires complete isolation from the power utility. Not just power isolation, but also removal of any neutral or other such ground connections extending outside the grounding system. This test is the most suitable test for large grounding systems and is also suitable for small electrodes. The induced frequency test can be performed while power is on and actually requires the utility to be connected to the grounding system under test. This test is accurate only for small electrodes, as it uses frequencies in the kiloHertz range, which see long conductors as inductive chokes and therefore do not reflect the ٦٠ Hz resistance of the entire grounding system.

١١.٥.١ Fall-of-Potential Method or ٣-Point Test

The ٣-point or fall-of-potential method is used to measure the resistance-to-ground of existing grounding systems. The two primary requirements to successfully complete this test are the ability to isolate the grounding system from the utility neutral and knowledge of the diagonal length of the grounding system (i.e. a ١٠' x ١٠' grounding ring would have a ١٤' diagonal length). In this test, a short probe, referred to as probe Z, is driven into the earth at a distance of ten times (١٠X) the diagonal length of the grounding system (rod X). A second probe (Y) is placed in-line at a distance from rod X equal to the diagonal length of the grounding system.



At this point, a known current is applied across X & Z, while the resulting voltage is measured across X & Y. Ohm's Law can then be applied (R=V/I) to calculate the measured resistance. Probe Y is then moved out to a distance of ٢X the diagonal length of the grounding system, in-line with X & Z, to repeat the resistance measurement at the new interval. This will continue, moving probe Y out to ٣X, ٤X, ... ٩X the diagonal length to complete the ٣–point test with a total of nine (٩) resistance measurements.

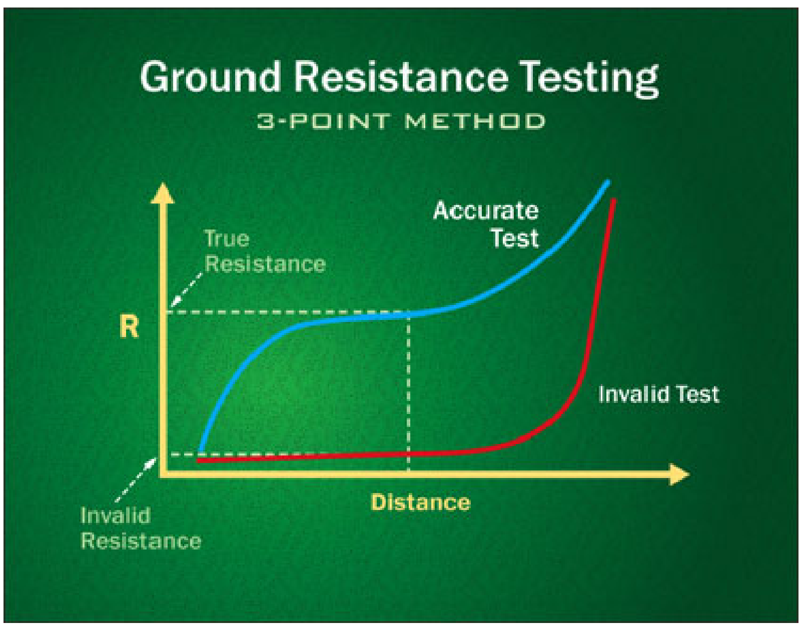


١١.٥.٢ Graphing & Evaluation

The ٣-point test is evaluated by plotting the results as data points with the distance from rod X along the X-axis and the resistance measurements along the Y-axis to develop a curve. Roughly midway between the center of the electrode under test and the probe Z, a plateau or "flat spot" should be found, as shown in the graph. The resistance of this plateau (actually, the resistance measured at the location ٦٢% from the center of the electrode under test, if the soil is perfectly homogeneous) is the resistance-to-ground of the tested grounding system.

١١.٥.٣ Invalid Tests

If no semblance of a plateau is found and the graph is observed to rise steadily the test is considered invalid. This can be due to the fact that probe Z was not placed far enough away from rod X, and can usually indicate that the diagonal length of the grounding system was not determined correctly. If the graph is observed to have a low plateau that extends the entire length and only rises at the last test point, then this also may be also considered invalid. This is because the utility or telecom neutral connection remains on the grounding system.



١١.٥.٤ Induced Frequency Testing or Clamp-On Testing

The Induced Frequency testing or commonly called the "Clamp-On" test is one of the newest test methods for measuring the resistance-to-ground of a grounding system or electrode. This test uses a special transformer to induce an oscillating voltage (often ١.٧ kHz) into the grounding system. Unlike the ٣-point Test which requires the grounding system to be completely disconnected and isolated before testing, this method requires that the grounding system under test be connected to the electric utilities (or other large grounding system such as from the telephone company) grounding system (typically via the neutral return wire) to provide the return path for the signal. This test is the only test that can be used on live or 'hot" systems. However, there are some limitations, primarily being:

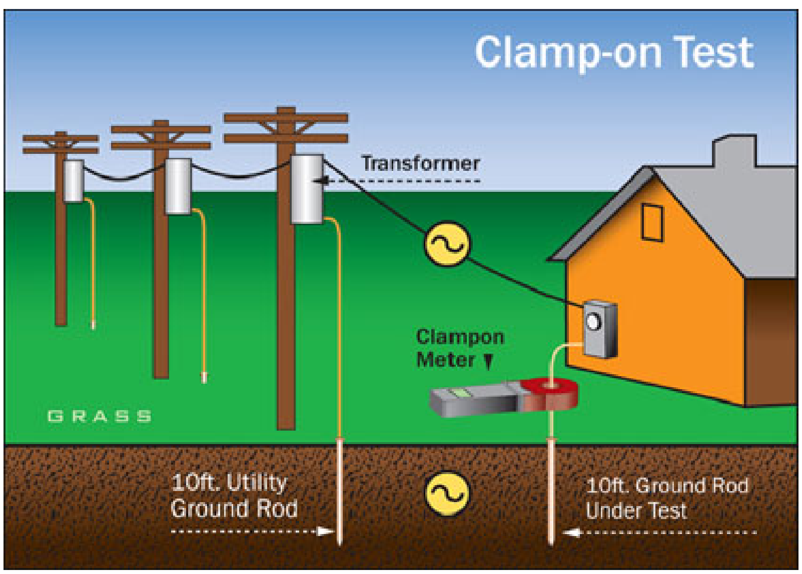
١. The amount of amperage running through the tested system must be below the equipment manufacturer's limits.
٢. The test signal must be injected at the proper location, so that the signal is forced through the grounding system and into the earth.

٣. This instrument actually measures the sum of the resistance of the grounding system under test and the impedance of the utility neutral grounding, including the neutral wiring. Due to the high frequency used, the impedance of the neutral wiring is non-negligible and can be greater than the ground resistance of a very low resistance grounding system, which can therefore not be measured accurately.
٤. The ground resistance of a large grounding system at ٦٠ Hz can be significantly lower than at ١.٧ kHz.

Many erroneous tests have been conducted where the technician only measured metallic loops and not the true resistance-to-ground of the grounding system. The veracity of the Induced Frequency Test has been questioned due to testing errors, however when properly applied to a small to medium sized, self-standing grounding system, this test is rapid and reasonably accurate.

١١.٥.٥ Test Application

The proper use of this test method requires the utility neutral to be connected to a wye-type transformer. The oscillating voltage is induced into the grounding system at a point where it will be forced into the soil and return through the utility neutral. Extreme caution must be taken at this point as erroneous readings and mistakes are often made. The most common of these occur when clamping on or inducing the oscillating voltage into the grounding system at a point where a continuous metallic path exists back to the point of the test. This can result in a continuity test being performed rather than a ground resistance test.



Understanding the proper field application of this test is vital to obtaining accurate results. The induced frequency test can test grounding systems that are in use and does not require the interruption of service to take measurements.

١١.٥.٦ Ground Resistance Monitoring

Ground resistance monitoring is the process of automated timed and/or continuous resistance-to ground measurement. These dedicated systems use the induced frequency test method to continuously monitor the performance of critical grounding systems. Some models may also provide automated data reporting. These new meters can measure resistance-to-ground and the current that flows on the grounding systems that are in use. Another benefit is that it does not require interruption of the electrical service to take these measurements.

١١.٦ What Is Ground Potential Rise, Earth Potential Rise And What Is A Ground Potential Rise Study?

Ground Potential Rise (GPR) or Earth Potential Rise is a phenomenon that occurs when large amounts of electricity enter the earth. This is typically caused when substations or high-voltage towers fault, or when lightning strikes occur (fault current). When currents of large magnitude enter the earth from a grounding system, not only will the grounding system rise in electrical potential, but so will the surrounding soil as well.

The voltages produced by a Ground Potential Rise or Earth Potential Rise event can be hazardous to both personnel and equipment. As described earlier, soil has resistance know as soil resistivity which will allow an electrical potential gradient or voltage drop to occur along the path of the fault current in the soil. The resulting potential differences will cause currents to flow into any and all nearby grounded conductive bodies, including concrete, pipes, copper wires and people.

١١.٦.١ Ground Potential Rise Study

A Ground Potential Rise Study is the process of automated timed and/or continuous resistance-to ground measurement. These dedicated systems use the induced frequency test method to continuously monitor the performance of critical grounding systems. Some models may also provide automated data reporting. These new meters can measure resistance-to-ground and the current that flows on the grounding systems that are in use. Another benefit is that it does not require interruption of the electrical service to take these measurements.

١١.٦.٢ Ground Potential Rise (GPR) Definitions

Ground Potential Rise or Earth Potential Rise (as defined in IEEE Standard ٣٦٧) is the product of a ground electrode impedance, referenced to remote earth, and the current that flows through that electrode impedance.

Ground Potential Rise or Earth Potential Rise (as defined by IEEE Standard ٨٠-٢٠٠٠) is the maximum electrical potential that a (substation) grounding grid may attain relative to a distant grounding point assumed to be at potential of remote earth. This voltage, GPR, is equal to the maximum grid current times the grid resistance.

Ground Potential Rise or Earth Potential Rise events are a concern wherever electrical currents of large magnitude flow into the earth. This can be at a substation, high-voltage tower or pole, or a large transformer. In cases where an Earth Potential Rise event may be of special concern, grounding precautions are required to ensure personnel and equipment safety. Electrical potentials in the earth drop abruptly around the perimeter of a grounding system, but do not drop to zero. In fact, in a perfectly homogeneous soil, soil potentials are inversely proportional to the distance from the center off the grounding system, once one has reached a distance that is a small number of grounding system dimensions away.

١١.٦.٣ The Earth Potential formula is as follows:

- Earth Potential = Soil Resistivity x Current / (٢ x PI x Distance)

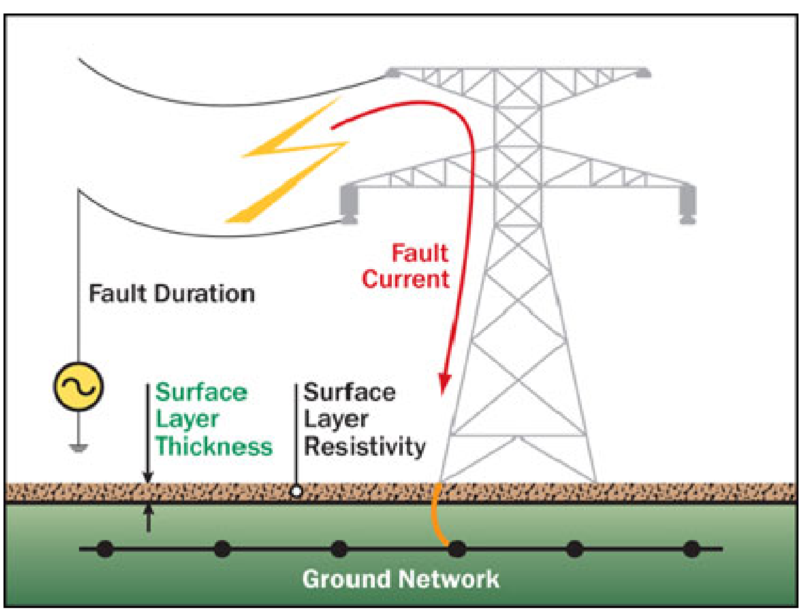
Where Earth Potential is in volts, Soil Resistivity is in ohm-meters, Current is the current flowing into the soil from the grounding system, in amperes, PI is ٣.١٤١٥٩... and Distance is in meters.

Probably the most commonly noted Ground Potential Rise or Earth Potential Rise event involves the death of cows in a field during a lightning strike. Imagine lightning striking the center of an open field where cows are standing. The current injected into the earth flows radially away from the strike point, in all directions, creating voltage gradients on the surface of the earth, also in a radial direction. All the cows facing the lightning strike would have their fore hooves closer to the strike point than their rear hooves. This would result in a difference of potential between their fore and rear legs, causing current to flow through their bodies, including the heart area, and killing the cow. On the other hand, those cows with their flanks turned towards the lighting strike would have a greater chance of surviving, as the distance between their fore legs and therefore the voltage applied between them, would be relatively small, resulting in a lesser current flow.

A Ground Potential Rise Study is typically conducted on substations and high-voltage towers to measure Earth Potential. Substations have relatively large grounding areas, especially when compared to high-voltage towers and poles. Towers and poles represent by far the most potentially dangerous and difficult Ground Potential Rise situations to handle and are often not protected, unless they are located in high exposure areas or have equipment installed at ground level at which service personnel might be required to work.

١١.٦.٤ Ground Potential Rise Study

The primary purpose of a Ground Potential Rise Study is to determine the level of hazard associated with a given high-voltage location for personnel and/or equipment. When the degree of hazard is identified, the appropriate precautions must be made to make the site safe. To do this, the engineer must identify what the minimum grounding system for each location will be. The engineer must also take into consideration all local and federal guidelines, including utility company and other requirements.



For example: Many utility companies require at a minimum that a simple ground ring be installed at least ١٨ inches below ground and ٣ feet from the perimeter of all metal objects. This ground ring is also referred to as a counterpoise.

Once the minimum grounding system is identified, the engineer can run a Ground Potential Rise or Earth Potential Rise Analysis and identify the extent of any electrical hazards.

Typically, items reported in a Ground Potential Rise Study will include the following: the square footage, size and layout of the proposed grounding grid, resistance-to-ground of the proposed grounding system, the estimated fault current that would flow into the grounding system, Ground Potential Rise (in volts) at the site, ٣٠٠ Volt Peak line, the X/R Ratio, and the fault clearing time in seconds. Step and touch potential voltages are usually computed as well, as these are the primary indicators of safety.

The grounding engineer needs three (٣) pieces of information to properly conduct a Ground Potential Rise Study:

١. Soil resistivity data from a Soil Resistivity Test
٢. Site drawings with the proposed construction
٣. Electrical data from the power company

١١.٦.٥ Soil Resistivity Test

The soil resistivity test data should include apparent resistivity readings at pin spacings ranging from ٠.٥ or ١ ft to as many as three grounding grid diagonals, if practical. Touch and step voltages represent the primary concern for personnel safety. Understanding the characteristics of the soil at depths ranging from immediately underfoot to one or more grid dimensions is required for a cost-effective and safe grounding system to be designed.

١١.٦.٦ Site Drawings

The proposed site drawings should show the layout of the high-voltage tower or substation, and any additional construction for new equipment that may be occurring on the site, including fencing and gate radius. Incoming power and Telco runs should also be included. In the case of high-voltage towers, the height and spacing of the conductors carried on the tower, and any overhead ground wires that may be installed on the tower, need to be detailed during the survey. This information is needed to properly address all the touch and step voltage concerns that may occur on the site.

١١.٦.٧ Electric Utility Data

The electric utility company needs to provide electrical data regarding the tower or substation under consideration. This data should include the name of the substation or the number of the tower, the voltage level, the subtransient X/R ratio, and the clearing times. In the case of towers, the line names of the substations involved, the amount of current contributed by each substation in the event of a fault, and the type and positions of the overhead ground wires, if any, with respect to the phase conductors installed on each tower or pole. If overhead ground wires are present, tower or pole ground resistances along the line are of interest as well, be they measured, average or design values.

This information is important, as high-voltage towers have small ground area, yet handle very large amounts of electricity. Knowing if a tower has an overhead ground wire is important, because the overhead wire will carry away a percentage of the current, which will depend on the overhead ground wire type and ground resistances of adjacent towers, to other towers in the run, reducing the GPR event. Additionally, towers with overhead ground wires tend to have shorter clearing times. The same holds for substations: overhead ground wires on transmission lines and neutral wires on distribution lines can significantly reduce the magnitude of fault current that flows into the substation grounding system during fault conditions.

The following information is required from the utility company:

١. Phase-to-ground fault current contributed by each power line circuit
٢. Fault clearing time
٣. Line voltage
٤. Subtransient X/R ratio
٥. The make/type/number of overhead ground wires on each tower/pole line and position with respect to the phase conductors
٦. Ground wire continuity and bonding configuration back to the tower and substation
٧. The average distance from tower-to-tower and tower-to-substation
٨. Typical tower/pole ground resistance: measured or design values

As-built drawings are often acquired and are useful for towers with existing grounding systems. They are also useful in the case of modifications and upgrades to existing substations, which will have extensive grounding systems already installed.

١١.٦.٨ Personnel Safety during Ground Potential Rise or Earth Potential Rise Events

The grounding engineer will be required to develop safety systems to protect any personnel working where Ground Potential Rise hazards are known to exist. Federal Law mandates that all known hazards must be eliminated from the work place for the safety of workers. It is the engineer's choice on which voluntary standards to apply in order to comply with the law. Federal law ٢٩ CFR ١٩١٠.٢٦٩ specifically states that Step and Touch Potentials must be eliminated on transmission and distribution lines that include any related communication equipment.

Substations are always considered workplaces and Step and touch Potentials must be eliminated. Transmission and distribution towers or poles are not always considered work places and therefore are often exempt from these requirements. Take, for example, a lonely tower on a mountain side or in the middle of the desert: these towers are not typically considered workplaces. However, any high-voltage tower or pole becomes a workplace as soon as equipment is installed that is not related to the electric utility company and requires outside vendors to support the new equipment. Cellular telecommunications, environmental monitoring, and microwave relay equipment are good examples of equipment that, when installed on a high-voltage tower, turns the tower into a work place. This would make the elimination of Step and Touch Potentials required.

١١.٦.٩ Hazardous Voltages

Fibrillation Current is the amount of electricity needed to cause cardiac arrest, from which recovery will not spontaneously occur, in a person and is a value based on statistics. IEEE Std ٨٠-٢٠٠٠ provides a method to determine the pertinent value of Fibrillation Current for a safety study, along with a good explanation of how it is derived. Many different methods exist for calculating Fibrillation Current; however the ٥٠kg IEEE method is the most commonly used in North America. The formula used shows that the Fibrillation Current level is inversely proportional to the square root of the fault duration; however, it must be increased by a correction factor, based on the subtransient X/R ratio, which can be quite large for shorter fault durations. If personnel working at a site during fault conditions experience voltages that will cause a current less than the Fibrillation Current to flow in their bodies, then they are considered safe. If a worker will experience a greater voltage than is acceptable, additional safety precautions must be taken.

The subtransient X/R ratio at the site of the fault is important in calculating the acceptable Fibrillation Current and to determine the maximum allowable Step and Touch Potentials that can occur at any given site.

Fault Duration is a very necessary piece of data for properly calculating maximum allowable Step and Touch Potentials. The Fault Duration is the amount of time required for the power company to shut off the current in the event of a fault.

Ultimately the engineer must determine two (٢) things:

١. The site-specific maximum allowable voltage that a person can safely withstand
٢. The actual voltages that will be experienced at the site during a fault

Each site will have different levels of voltages for both of the above. Unfortunately, we cannot simply say that a human being can withstand X-level of voltages and use that value all the time, since this voltage is determined by the surface layer resistivity, the fault duration and the subtransient X/R ratio. Additionally as each site has different fault durations and different soil conditions, it is critical that calculations be made for each and every possible fault location.

١١.٧ What Is Step and Touch Potential and Reducing Resistance To Ground?

١١.٧.١ Step Potential

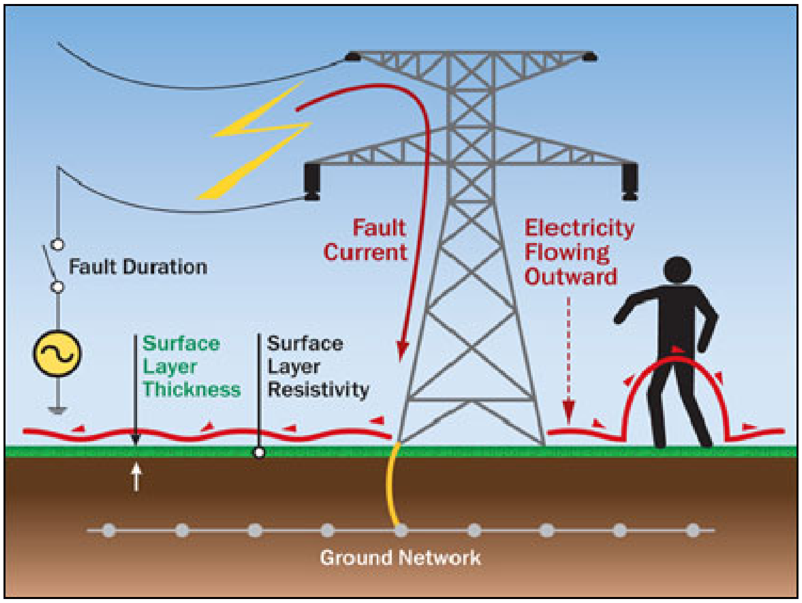
Step potential is the step voltage between the feet of a person standing near an energized grounded object. It is equal to the difference in voltage, given by the voltage distribution curve, between two points at different distances from the electrode. A person could be at risk of injury during a fault simply by standing near the grounding point.

١١.٧.٢ Touch Potential

Touch potential is the touch voltage between the energized object and the feet of a person in contact with the object. It is equal to the difference in voltage between the object and a point some distance away. The touch potential or touch voltage could be nearly the full voltage across the grounded object if that object is grounded at a point remote from the place where the person is in contact with it. For example, a crane that was grounded to the system neutral and that contacted an energized line would expose any person in contact with the crane or its uninsulated load line to a touch potential nearly equal to the full fault voltage.

١١.٧.٣ Step Potential

When a fault occurs at a tower or substation, the current will enter the earth. Based on the distribution of varying resistivity in the soil (typically, a horizontally layered soil is assumed) a corresponding voltage distribution will occur. The voltage drop in the soil surrounding the grounding system can present hazards for personnel standing in the vicinity of the grounding system. Personnel "stepping" in the direction of the voltage gradient could be subjected to hazardous voltages.



In the case of Step Potentials or step voltage, electricity will flow if a difference in potential exists between the two legs of a person. Calculations must be performed that determine how great the tolerable step potentials are and then compare those results to the step voltages expected to occur at the site.

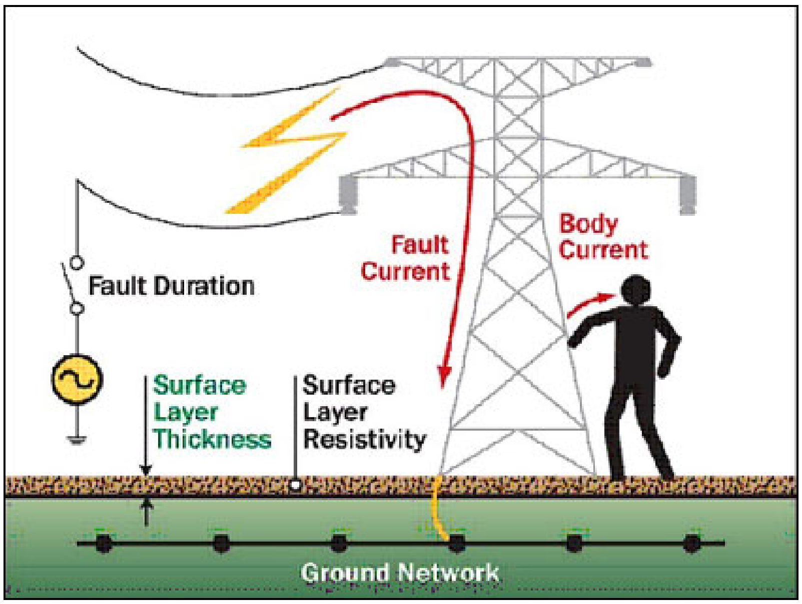
Hazardous Step Potentials or step voltage can occur a significant distance away from any given site. The more current that is pumped into the ground, the greater the hazard. Soil resistivity and layering plays a major role in how hazardous a fault occurring on a specific site may be. High soil resistivities tend to increase Step Potentials. A high resistivity top layer and low resistivity bottom layer tends to result in the highest step voltages close to the ground electrode: the low resistivity bottom layer draws more current out of the electrode through the high resistivity layer, resulting in large voltage drops near the electrode. Further from the ground electrode, the worst case scenario occurs when the soil has conductive top layers and resistive bottom layers: in this case, the fault current remains in the conductive top layer for much greater distances away from the electrode.

Fault clearing time is an important factor to consider as well. The more time it takes the electric utility company to clear the fault, the more likely it is for a given level of current to cause the human heart to fibrillate.

An important note to remember is that most power companies use automated re-closers. In the event of a fault, the power is shut off and then automatically turned back on. This is done in case the faults occurred due to an unfortunate bird that made a poor choice in where to rest, or dust that may have been burned off during the original fault. A few engineers believe that Fibrillation Current for Step Potentials must be far greater than Touch Potentials, as current will not pass through any vital organs in the former case. This is not always true as personnel that receive a shock due to Step Potentials may fall to the ground, only to be hit again, before they can get up, when the automatic re-closers activate.

١١.٧.٤ Touch Potential

When a fault occurs at a tower or substation, the current will pass through any metallic object and enter the earth. Those personnel "touching" an object in the vicinity of the GPR will be subjected to these touch voltages which may be hazardous.



For example if a person happens to be touching a high-voltage tower leg when a fault occurs, the electricity would travel down the tower leg into the person's hand and through vital organs of the body. It would then continue on its path and exit out through the feet and into the earth. Careful analysis is required to determine the acceptable Fibrillation Currents that can be withstood by the body if a fault were to occur.

Engineering standards use a one-meter (٣.٢٨ ft) reach distance for calculating Touch Potentials. A two-meter (٦.٥٤ ft) reach distance is used when two or more objects are inside the GPR event area. For example, a person could be outstretching both arms and touching two objects at once such as a tower leg and a metal cabinet. Occasionally, engineers will use a three-meter distance to be particularly cautious, as they assume someone may be using a power tool with a power cord ٣ meters in length.

The selection of where to place the reference points used in the Touch Potential or touch voltage calculations are critical in getting an accurate understanding of the level of hazard at a given site. The actual calculation of Touch Potentials uses a specified object (such as a tower leg) as the first reference point. This means that the further away from the tower the other reference point is located, the greater the difference in potential. If you can imagine a person with incredibly long arms touching the tower leg and yet standing many dozens of feet away, you would have a huge difference in potential between their feet and the tower. Obviously, this example is not possible: this is why setting where and how far away the reference points used in the touch calculation is so important and why the one-meter rule has been established.

Mitigating Step and Touch Potential hazards is usually accomplished through one or more of the following three (٣) main techniques:

١. Reduction in the Resistance to Ground of the grounding system
٢. Proper placement of ground conductors
٣. The addition of resistive surface layers

Understanding the proper application of these techniques is the key to reducing and eliminating any Ground Potential Rise hazards. Only through the use of highly sophisticated ٣-dimensional electrical simulation software that can model soil structures with multiple layers and finite volumes of different materials, can the engineer accurately model and design a grounding system that will safely handle high-voltage electrical faults.

١١.٧.٥ Reducing Resistance to Ground

Reducing resistance to ground (RTG) of the site is often the best way to reduce the negative effects of any Ground Potential Rise event, where practical. The Ground Potential Rise is the product of the fault current flowing into the grounding system times the resistance to ground of the grounding system. Thus, reducing the Ground Potential Rise will reduce the Ground Potential Rise to the degree that the fault current flowing into the grounding system does increase in response to the reduced Ground Potential Rise. For example, if the fault current for a high-voltage tower is ٥,٠٠٠ amps and the resistance to ground of the grounding system is ١٠-ohms, the Ground Potential Rise will be ٥٠,٠٠٠ volts. If we reduce the resistance to ground of the grounding system down to ٥-ohms and the fault current increases to ٧,٠٠٠ amps as a result, then the Ground Potential Rise will become ٣٥,٠٠٠ volts.

As seen in the example above, the reducing resistance to ground can have the effect of allowing more current to flow into the earth at the site of the fault, but will always result in lower Ground Potential Rise values and step and touch voltages at the fault location. On the other hand, further away from the fault location, at adjacent facilities not connected to the faulted structure, the increase in current into the earth will result in greater current flow near these adjacent facilities and therefore an increase in the Ground Potential Rise, touch voltages and step voltages at these facilities. Of course, if these are low to begin with, an increase may not represent a problem, but there are cases in which a concern may exist. Reducing the resistance to ground can be achieved by any number of means as discussed earlier in this chapter.

١١.٧.٦ Proper Placement of Ground Conductors

A typical specification for ground conductors at high-voltage towers or substations is to install a ground loop around all metallic objects, connected to the objects; keep in mind that it may be necessary to vary the depth and/or distance that ground loops are buried from the structure in order to provide the necessary protection. Typically these ground loops require a minimum size of ٢/٠ AWG bare copper conductor buried in direct contact with the earth and ٣-ft from the perimeter of the object, ١٨ inches below grade. The purpose of the loop is to minimize the voltage between the object and the earth surface where a person might be standing while touching the object: i.e., to minimize Touch Potentials.

It is important that all metallic objects in a GPR environment be bonded to the ground system to eliminate any difference in potentials. It is also important that the resistivity of the soil as a function of depth be considered in computed touch and step voltages and in determining at what depth to place conductors. For example, in a soil with a dry, high resistivity surface layer, conductors in this layer will be ineffective; a low resistivity layer beneath that one would be the best location for grounding conductors. On the other hand, if another high resistivity layer exists further down, long grounding rods or deep wells extending into this layer will be ineffectual.

It is sometimes believed that placing horizontal grounding loop conductors very close to the surface results in the greatest reduction in Touch Potentials. This is not necessarily so, as conductors close to the surface are likely to be in drier soil, with a higher resistivity, thus reducing the effectiveness of these conductors. Furthermore, while Touch Potentials immediately over the loop may be reduced, Touch Potentials a short distance away may actually increase, due to the decreased zone of influence of these conductors. Finally, Step Potentials are likely to increase at these locations: indeed, Step Potentials can be a concern near conductors that are close to the surface, particularly at the perimeter of a grounding system. It is common to see perimeter conductors around small grounding systems buried to a depth of ٣-ft below grade, in order to address this problem.

١١.٧.٧ Reducing Step and Touch Potential Hazards

One of the simplest methods of reducing Step and Touch Potential hazards is to wear Electric Hazard Shoes. When dry, properly rated electric hazard shoes have millions of ohms of resistance in the soles and are an excellent tool for personnel safety. On the other hand, when these boots are wet and dirty, current may bypass the soles of the boots in the film of material that has accumulated on the sides of the boot. A wet leather boot can have a resistance on the order of ١٠٠ ohms. Furthermore, it cannot be assumed that the general public, who may have access to the outside perimeter of some sites, will wear such protective gear.

Another technique used in mitigating Step and Touch Potential hazards is the addition of more resistive surface layers. Often a layer of crushed rock is added to a tower or substation to provide a layer of insulation between personnel and the earth. This layer reduces the amount of current that can flow through a given person and into the earth. Weed control is another important factor, as plants become energized during a fault and can conduct hazardous voltages into a person. Asphalt is an excellent alternative, as it is far more resistive than crushed rock, and weed growth is not a problem. The addition of resistive surface layers always improves personnel safety during a GPR event.

١١.٧.٨ Telecommunications in High-Voltage Environments

When telecommunications lines are needed at a high-voltage site, special precautions are required to protect switching stations from unwanted voltages. Running any copper wire into a substation or tower is going to expose the other end of the wire to hazardous voltages and certain precautions are required.

Industry standards regarding these precautions and protective requirements are covered in IEEE Standard ٣٨٧, IEEE Standard ٤٨٧, and IEEE Standard ١٥٩٠.These standards require that a Ground Potential Rise study be conducted so that the ٣٠٠-volt peak line can be properly calculated.

To protect the cell site and communication towers, telecommunication standards require that fiber-optic cables be used instead of copper wires within the ٣٠٠-volt peak line. A copper-to-fiber conversion box must be located outside the GPR event area at a distance in excess of the ٣٠٠-Volt Peak or ٢١٢-Volt RMS line. This is known in the industry as the “٣٠٠-volt line.” This means that based on the calculation results, copper wire from the telecommunications company may not come any closer than the ٣٠٠-volt peak distance. This is the distance where copper wire must converted over to fiber-optic cable. This can help prevent any unwanted voltages from entering the phone companies' telecommunications network.

The current formulae for calculating the ٣٠٠-volt line, as listed in the standards, has led to misinterpretation and divergences of opinion, resulting in order-of-magnitude variations in calculated distances for virtually identical design input data. Furthermore, operating experience has shown that a rigorous application of theory results in unnecessarily large distances. This has caused many compromises within the telecommunications industry. The most noted one is a newer standard, IEEE Standard ١٥٩٠-٢٠٠٣, that lists a ١٥٠-meter (~٥٠٠-foot) mark as a default distance, if a ground potential rise study has not been conducted at a given location.